Earthquake-Induced Slope-Failure Hazards for the Wellsville Quadrangle, Central Cache Valley, Utah

by

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UTAH GEOLOGICAL SURVEY

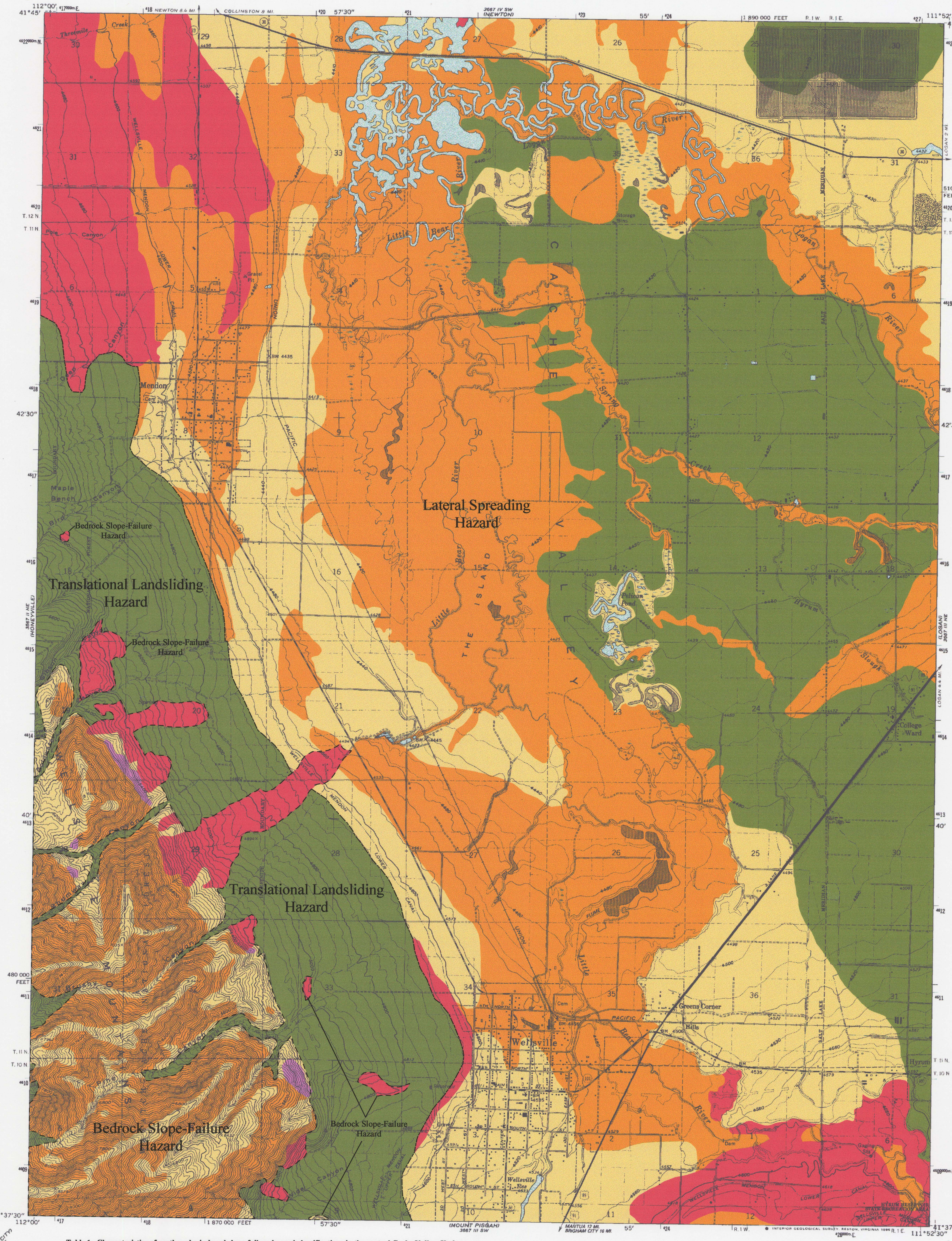
Contour Interval 40 Feet

Scale 1:24,000

1 0 1 2 Miles

5,000 0 5,000 10,000 Feet

1 0 1 2 Kilometers



DISCUSSION

Downslope movements of rock or soil under the influence of gravity may be triggered by earthquake ground shaking. This map shows the relative hazard on slopes of earthquake-induced failure. Seismic slope-instability hazards are mapped in three groups: (1) lateral spreads on soil slopes less than 6 percent, (2) translational landslides on soil slopes greater than 6 percent, and (3) failures of rock slopes (table 1). Lateral spreads are characterized by surficial blocks of sediment which are displaced laterally down gentle slopes as a result of liquefaction in a subsurface layer. Translational landslides are characterized by one or more discrete blocks of sediment which are displaced down steeper slopes on a generally planar surface of rupture in weak material. Rock-slope failures are characterized by the downslope movement of intact bedrock and weathered residual material that retain significant components of original rock structure.

This map was compiled by collecting relevant data from geotechnical boreholes, supplementing these data with information from water wells and geologic maps (McCalpin, 1989; Lowe and Galloway, 1993; Evans and others, 1996; Solomon, 1999) and, where appropriate geotechnical data are lacking, estimating the necessary values from relationships to known material properties. The data were then integrated into a Geographic Information Systems (GIS) format using ArcView GIS v3.2 (Environmental Systems Research Institute, Inc., 1999) and ArcView Spatial Analyst v2.0a (Environmental Systems Research Institute, Inc., 2000) software. We calculated the displacement expected from lateral spreads using the empirical equation of Youd and others (1999) determined from observations at sites of historical lateral spreading, applying methods developed by Mabey and others (1993) for mapping earthquake hazards in Portland, Oregon, to estimate values of the necessary geotechnical parameters. We calculated Newmark displacements, a relative measure of the potential for translational landslides, using the empirical equation of Jibson and others (1998) determined from data collected during and after the 1994 Northridge, California earthquake. We assessed the stability of rock slopes using the method of Keefer (1993), based on associations between landslide concentrations and slope characteristics documented from historical earthquakes.

When using this map, several important qualifiers must be noted:

- Youd and others (1999) provide equations to calculate ground displacement from lateral spreading for two conditions: ground-slope conditions (where surficial blocks of material are transported down gentle slopes) and free-face conditions (where surficial blocks of material are transported in the direction of an abrupt topographical scarp). This map estimates lateral-spread displacement only for ground-slope conditions. Displacement due to free-face conditions is not significant at the map scale but should be considered where appropriate for site-specific investigations (table 2), such as in areas near incised streams or steep embankments.

- Ground displacements calculated for lateral spreading depend upon earthquake magnitude, distance to the earthquake source, texture of liquefiable sediments, and ground-water depth. For this map, we assume an earthquake of magnitude 6.5 occurs at a constant distance of 5 kilometers from each map point. This is a reasonable scenario given the paleoseismic history of the region, but larger earthquakes are possible. To adjust displacements for a different earthquake magnitude and distance, use the appropriate multiplication factor from table 3. We also assume that liquefiable sediments consist of silty sand with a fines content of 30 percent and a median grain size of 0.2 millimeters. Because textures in natural settings are both vertically and horizontally variable and we have little data on sediment textures, site-specific geotechnical investigations are required to develop accurate estimates of texture. Once a site-specific value is determined, use the appropriate multiplication factor from table 4 to adjust displacements calculated for this study. Multiplication factors in both tables are calculated using the equation of Youd and others (1999) for ground-slope conditions. Site-specific investigations are also needed for accurate measurement of ground-water depth.

- Liquefaction-induced ground displacement may also be caused by flow failure, ground oscillation, and ground settlement. This map does not estimate potential ground displacement that may result from these mechanisms. Except for some locally steep river banks, ground slopes in liquefiable areas of the central Cache Valley are too gentle to be susceptible to flow failure. No widely accepted techniques for estimating transient lateral displacements generated from liquefaction-induced ground oscillation exist, but Mabey and others (1993) suggest using the greater of a few tenths of a meter or the predicted displacement for lateral spread as a preliminary estimate. Techniques for estimating settlements in granular soils during earthquakes (Tokimatsu and Seed, 1987; Ishihara and Yoshimine, 1992) were developed for clean sands and have not been fully verified for silty sands and sandy silts that commonly underlie the central Cache Valley. Mabey and others (1993) estimate that a 10-meter thick liquefiable layer of silty sand might be expected to generate settlements on the order of 0.1-0.5 meters during strong earthquakes. Smaller amounts of non-liquefaction-induced settlement could be generated in loose granular sediments above the water table.

- Ground displacements calculated for translational landsliding depend upon earthquake magnitude, peak ground accelerations, soil properties, and ground-water depth. For this map we assume an earthquake of magnitude 6.5 and a peak ground acceleration of 0.2 g. This is a reasonable scenario given the paleoseismic history of the region, but larger earthquakes and ground accelerations are possible. We also assume representative values for shear strength and dry density of slope materials within each surficial geologic unit, and infer the proportion of slope materials that are saturated. Site-specific investigations are required to determine accurate soil properties and ground-water depth.

- Slope-failure hazards indicate only the source zones of landslides (the parts of slopes that may fail). This map does not show how far downslope the failed material may travel before stopping. Proposed development in areas downslope of landslide source zones should consider this in site-specific investigations.

This map is intended primarily for regional planning purposes and should not be used as a substitute for site-specific geotechnical investigations conducted by qualified professionals. The map is not intended for use at scales other than the published scale. Map boundaries are based on limited data available prior to the date of publication, are approximate, and are subject to change as the quantity and quality of available data improve. The slope-failure hazard at any particular site may actually be higher or lower than shown because of geological variations within a hazard rating, gradational and approximate map boundaries, and the regional scale of this map.

A practical limit exists to the size of potential slope failures that can be considered in a regional mapping study. Small failures caused by locally steep terrain not readily apparent on the slope map, or pockets of colluvium on a steep rock slope, cannot be identified at this scale. The slope-failure ratings do not consider hazards caused by cuts, fills, or other alterations to the natural terrain.

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Table 1. Characteristics of earthquake-induced slope-failure hazard classifications in the central Cache Valley, Utah.

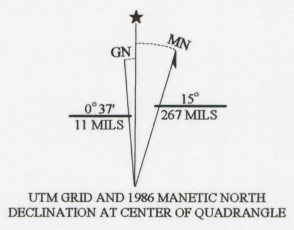
Slope-Failure Hazard	Slope-Failure Type								
	Lateral Spreading (soil slopes <6%)				Translational Landsliding (soil slopes >6%)			Bedrock Slope Failures[1] (all rock slopes)	
	Lateral Ground Displacement (cm)[2]	Depth to Ground Water (m)[3]	Expected Damage[4]	Predominant Geology[5]	Newmark Displacement (cm)[6]	Expected Deformation	Predominant Geology[5]	Slope Angle (°)	Predominant Geology[5]
Very High	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	>25	Tertiary rocks (soft bedrock) on steep slopes.
High	>30	<15	Severe damage or collapse, nonrepairable	Alluvial-levee and flood-plain deposits: Lake Bonneville nearshore and deltaic deposits; existing landslides.	>10	Slab failure likely.	Existing landslides	all	Existing landslides; Paleozoic rocks with open fissures along faceted mountain spurs, in major canyons, and in cliffs of resistant rock units at higher elevations.
Moderate	20-30	<15	Severe damage, repairable	Alluvial-flood-plain and fan deposits; Lake Bonneville nearshore and lake-bottom deposits.	6-10	Slab failure possible, ground cracking likely.	n.a.	>25	Paleozoic rocks (hard bedrock) without open fissures.
Low	10-20	<15		Lake Bonneville lake-bottom and nearshore deposits.	3-6	Ground cracking.		<25	All bedrock on low slopes.
Very Low	<10	<15 on very gentle slopes or >15 on all slopes	Little damage, repairable	Unconsolidated deposits.	<3	Deformation unlikely.	Unconsolidated deposits on piedmont slopes and in mountain canyons.	n.a.	n.a.

[1] Keefer (1993) observed that bedrock slopes lacking vegetation produced higher concentrations of landslides than vegetated bedrock slopes in otherwise similar materials for earthquakes with magnitudes less than 6.5. Decrease the slope-failure hazard for vegetated bedrock slopes by one class to determine their susceptibility to slope failure in earthquakes with magnitudes less than 6.5.
[2] Lateral displacements are valid only for the conditions assumed in the analysis. Displacements will vary with different earthquake magnitudes, distance to seismic sources, textures of liquefiable sediments, and ground-water depth. For this study, assumed conditions include an earthquake magnitude of 6.5, a distance of 5 km to the seismic source, and liquefiable sediments consisting of silty sand with a fines content of 30% and a median grain size of 0.2 mm. Site-specific investigations are required to determine accurate sediment textures and ground-water depth. To adjust estimated displacements for other conditions, multiply the displacements cited above by the appropriate factors from tables 3 and 4.
[3] Bjorklund and McGreevy (1971).
[4] Youd (1980).
[5] Boundaries of hazard areas do not coincide with geologic map units except for Tertiary units in very-high-hazard areas and existing landslides in high-hazard areas.
[6] Predicted Newmark displacements do not necessarily correspond directly to measurable slope movements in the field; they are a relative measure of field performance. The calculated displacements are only valid for the conditions assumed in the analysis. Displacements will vary with different earthquake magnitudes, peak ground accelerations, soil properties, and ground-water depth. For this study, assumed conditions include an earthquake magnitude of 6.5, a peak ground acceleration of 0.2 g (corresponding to a 10% probability of exceedance in 50 years), and representative values for shear strength and dry density of slope materials within each surficial geologic unit. Site-specific investigations are required to determine accurate soil properties and ground-water depth.
n.a. - not applicable

Table 2. Recommended requirements for site-specific investigations of mapped potential hazards.

Hazard	Soil Profile Type, Special-Study Area, or Potential-Hazard Area		Development Type			
			Essential Facilities, Special- and High-Occupancy Buildings	Industrial and Commercial Buildings (Other Than High-Occupancy)	Residential Subdivisions	Residential Single Lots
Amplified Ground Motion (Plate 1)	S_A,S_B		No	No	No	No
	S_C,S_D,S_E		Yes	Yes	No	No
	S_F		Yes	Yes	Yes	Yes
Surface Fault Rupture (Plate 1)	Inside Special-Study Area	Holocene Fault	Yes	Yes	Yes	Yes
		Quaternary Fault	Yes	No[1]	No[1]	No[1]
	Outside Special Study Area		Yes	No	No	No
Liquefaction (Plate 2)	High, Moderate		Yes	Yes	No[2]	No[2]
	Low, Very Low		Yes	No	No	No
	Not Susceptible		No	No	No	No
Slope Failure[3] (Plate 3)	Very High, High, Moderate		Yes	Yes	Yes	Yes
	Low, Very Low		Yes	No	No	No

[1] At a minimum, appropriate disclosure should be required.
[2] At a minimum, appropriate disclosure should be required. If a site is also within an area with high or moderate potential for lateral spreading (earthquake-induced slope failure caused by liquefaction on shallow slopes; see plate 3), a site-specific investigation is advised consistent with recommendations for slope-failure hazards.
[3] If permanent cuts have slopes steeper than 2H:1V (50 percent) and are not supported by retaining walls, cut slope stability must be addressed in accordance with the Uniform Building Code (International Conference of Building Officials, 1997, Appendix Chapter 33, section 3312).



UTM GRID AND 1986 MAGNETIC NORTH DECLINATION AT CENTER OF QUADRANGLE

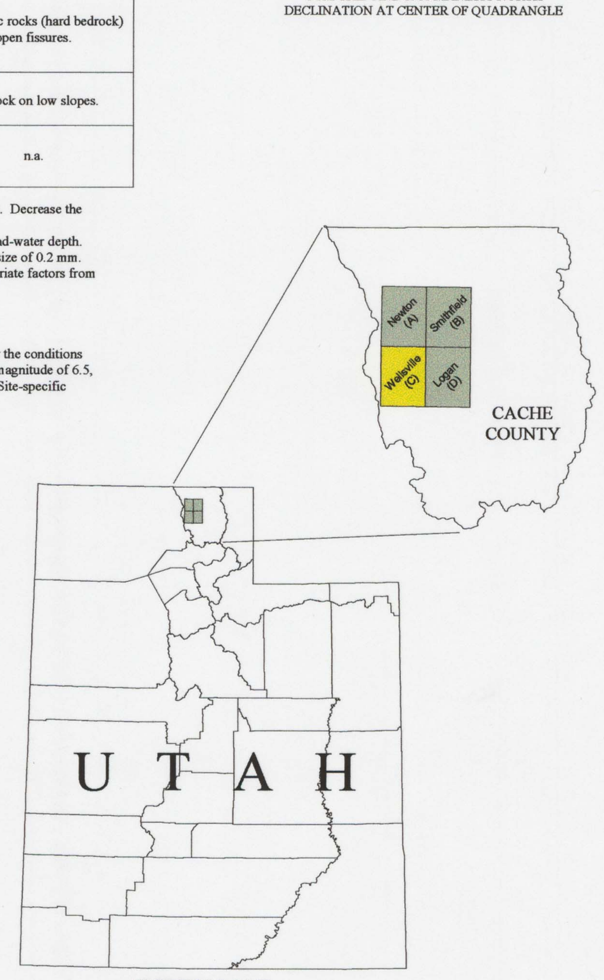


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Table 3. Multiplication factors to adjust lateral ground displacements for different earthquake magnitudes and distances to seismic source (using the equation of Youd and others [1999]). The default condition is shaded.

Earthquake Magnitude[1]	**6.0**	4.7	1.6	0.2	0.1	0	0	0	0	0	0	0	0	0
	6.5	8.9	4.9	1.0	0.1	0	0	0	0	0	0	0	0	0
	7.0	n.a.	10.3	3.7	1.7	0.6	0.3	0.1	0.1	0.1	0	0	0	0
	7.5	n.a.	n.a.	9.6	5.6	2.4	1.2	0.7	0.4	0.3	0.2	0.1	0.1	0.1
		0.25	**1**	**5**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
		Distance to Seismic Source (km)												

[1] Lateral-spread displacement appears to decrease markedly for earthquakes with magnitudes less than 6 (Bartlett and Youd, 1992).
n.a.– not applicable. Predicted displacements for large earthquakes near seismic sources are larger than normally expected and actual displacements are not documented by adequate data; extrapolation of multiplication factors to these distances may yield unreliable results (Bartlett and Youd, 1992).

Table 4. Multiplication factors to adjust lateral ground displacements for different textures of liquefiable sediments (modified from Mabey and others [1993] using the equation of Youd and others [1999]). The default condition is shaded.

Unified Soil Classification	Description	Fines Content (%)	Mean Grain Size (mm)	Factor
SP or SW	Fine Sand	<5	<0.4	2.5
	Medium Sand		0.4-0.7	2.0
	Coarse Sand		>0.7	1.5
SP-SM or SW-SM	Fine Sand with Silt	5-12	<0.4	2.5
	Medium Sand with Silt		0.4-0.7	2.0
	Coarse Sand with Silt		>0.7	1.5
SM	Silty Fine Sand	12-30	<0.4	2.0
	Silty Medium Sand		0.4-0.7	1.5
	Silty Coarse Sand		>0.7	1.0
	Very Silty Sand	30-50	<0.4	1.0
ML	Sandy Silt	50-70	<0.08	0.4

Map Symbols

- — — — — Boundary between areas analyzed for bedrock slope-failure and translational landsliding hazards.
- -——-——- Boundary between areas analyzed for translational landsliding and lateral spreading hazards.

Maps in this report:

- Amplified Earthquake Ground-Motion and Surface-Fault-Rupture Hazards (Plates 1A-1D)
- Liquefaction Hazards (Plates 2A-2D)
- Earthquake-Induced Slope-Failure Hazards (Plates 3A-3D)